

THE PHYSICS OF SOUND SCATTERING FROM, AND ATTENUATION THROUGH, COMPLIANT BUBBLY MIXTURES

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LONG-TERM GOALS

The goal of this research is to acquire a quantitative understanding, leading to predictive models, of the broader aspects of linear and nonlinear sound scattering and transmission in bubbly mixtures pertinent to the shallow water ocean acoustics scenario. This includes a conceptual understanding of the role played by stabilization mechanisms in bubble dynamics and longevity. Of particular interest is the phenomenological delineation of different regimes of behavior.

SCIENTIFIC OBJECTIVES

An objective specific to this proposal is the extension of the theory of sound transmission in bubbly liquids to derive bubbly-fluid attenuation characteristics for both small amplitude (linear response) and large amplitude (nonlinear response) forcing, ultimately incorporating the effects of contaminating surface-active solutes. A second goal is the development of a unique laboratory capability for the precise and accurate measurement of the frequency-dependent complex acoustic impedance of well-characterized bubble clouds. Cloud characterization implies the precise knowledge of all bubble population statistics, both spatially and size-wise.

APPROACH

All aspects of the work proceed in collaboration with W. Carey of NUWC/MIT; this project is the result of a joint planning letter submitted in FY 96. Also involved are BU Profs. G. McDaniel (data analysis and modeling) and R.G. Holt (bubble dynamics) as well as two BU graduate students. The approach involves a balance between modeling and experiments to predict and measure propagation and scattering characteristics. A core issue is the dynamics of a single bubble for both small and large amplitude forcing. This is handled numerically using either the Keller or Gilmore formulations for bubble dynamics. From this, the attributes of bubble behavior (mainly damping and resonance response) can be quantified and incorporated into a comprehensive description of sound propagation and scattering by extending the Wood-Foldy-Morse theories. The final step is to incorporate the effect of surface active materials by adapting numerical models developed by C.C.

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Church [J. Acoust. Soc. Am. **97**, 1510-21 (1995)] and by J. Allen [Ph.D. Dissertation, Dept. of Mech. Engineering., Univ. of Washington (1997)].

Laboratory experiments will measure the complex impedance of bubble distributions terminating sound-hard impedance tubes over frequencies ranging from well below to well above bubble resonance (of order 5 kHz - 250 kHz). The bubbly medium can be characterized optically using a stereo microscope. The frequency-dependent complex impedance of the termination derives from a measurement of the standing wave ratio for a series of normal modes. From this, the phase velocity and attenuation of the bubbly medium is obtained.

Experiments that focus on nonlinear propagation through bubbly media are planned for the out years. This will involve the use of an annular array (500 kHz) to insonify a bubbly liquid with short duration, large amplitude tone bursts. Of interest is the evolution from linear to shocked wavefront (and the resulting excess attenuation) as a function of bubble population statistics. Implications related to the formation of nonlinear beams in bubbly media will be addressed.

WORK COMPLETED

The effort to date has focused on four fronts: (1) Five papers either published or presented. (2) A final analysis of LF bubble cloud scattering data previously obtained at Lake Seneca is under way, in which the contributions of reverberation from nearby submerged objects is being accounted for in a rigorous fashion. (3) Development of bubble dynamics code based on the Keller formulation is nearing completion. This will be used to predict the details of individual bubble response, both on and off resonance. (4) Equipment procurement to support the experimental effort is under way and the initial design of the impedance tube is being fleshed out.

RESULTS

The scattering data analysis indicates the presence of a monopole scattering resonance (collective bubble cloud oscillation) that agrees well with theoretical predictions. Previously unexplained undulations in the target strength for the rising bubble cloud are due to acoustic interference between the bubble cloud and the bubbler itself. The bubble dynamics code is working well, and is capable of reproducing features of linear and nonlinear bubble response found in the literature.

IMPACT/APPLICATIONS

The notion that bubbles can be driven to pulsate collectively is important to any assessment of scattering and attenuation from oceanic bubble clouds and layers. The area of research is important to HF/SW noise and propagation, SW mine hunting sonars, high power acoustic arrays for MCM, and wake homing torpedoes.

RELATED PROJECTS

1. A collaboration with NUWC/Newport (R. Costa) and CSS/Panama City (K. Commander) on an instrument designed for *in situ* measurement of oceanic bubble dissolution rates.
2. A collaboration with APL/UW (S. Kargl) on the physics of nonlinear beam forming. The issues of enhanced nonlinearity and dissipation in bubbly water are key to both projects.
3. A collaboration with APL/UW (J. Allen & J. Riley) on developing new theories that describe the dynamics of bubbles in viscoelastic media. The PI was the research advisor for J. Allen, a UW Ph.D. student in Mechanical Engineering who completed his dissertation September 97.